

SHUTTLE HYPERVELOCITY IMPACT DATABASE

IAC-11.A6.3.7



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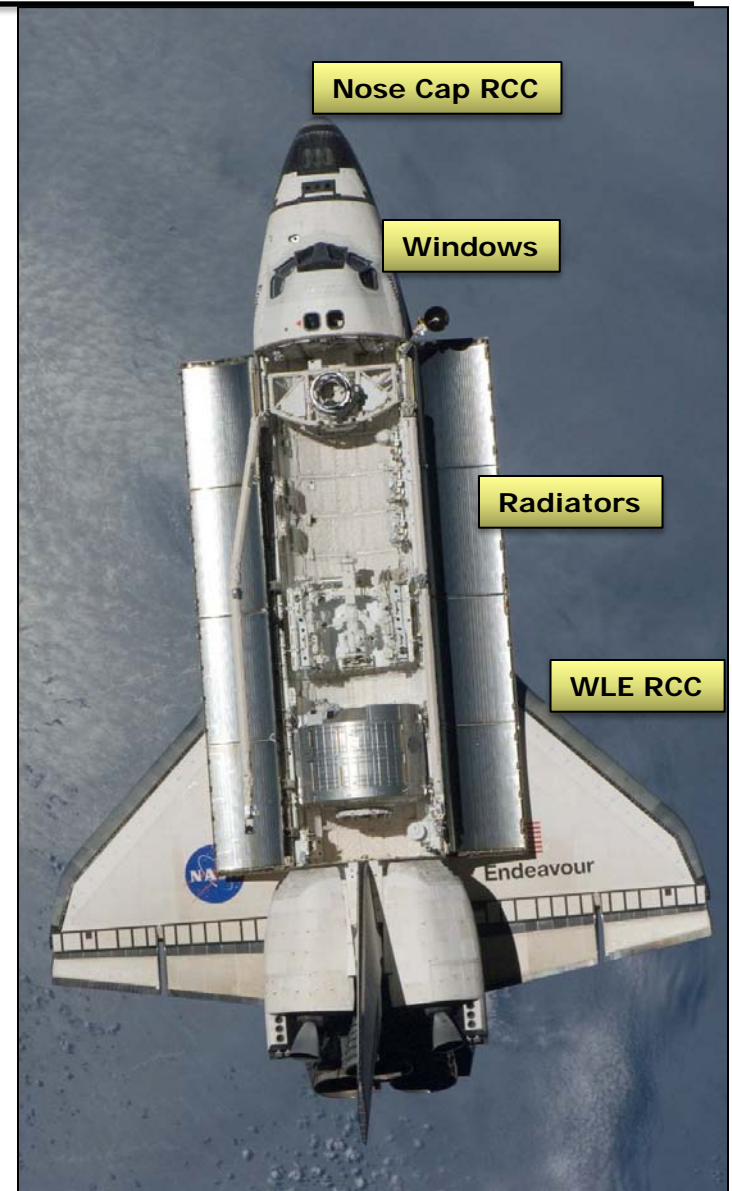
Eric L. Christiansen
NASA/JSC-KX

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NASA/JSC-KX

62nd International
Astronautical Congress
Cape Town, South Africa
3 – 7 October 2011

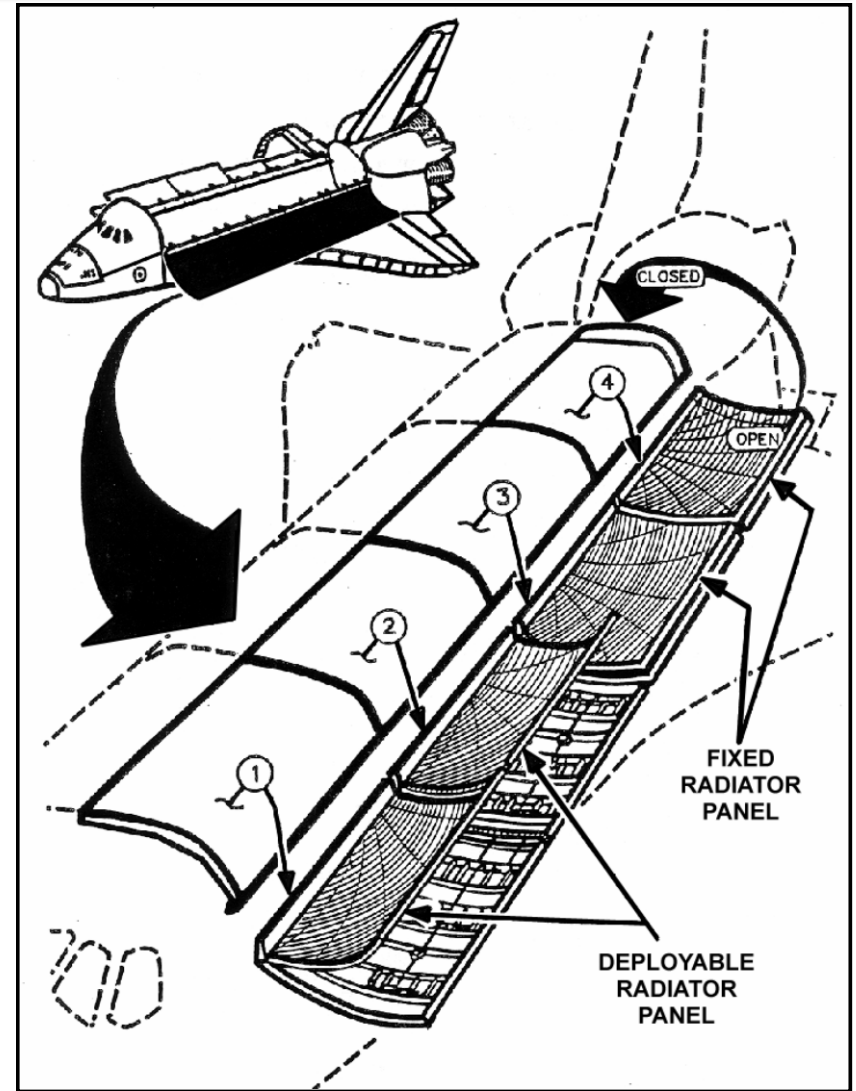
Introduction

- ❑ 135 shuttle missions between April 1981 & July 2011
- ❑ Post flight refurbishment includes micrometeoroid & orbital debris (MMOD) inspection
- ❑ Total surface area $\approx 1570 \text{ m}^2$
- ❑ Regions with detailed MMOD inspections
 - ❑ Payload Bay Door Radiators (7.6%)
 - ❑ Wing Leading Edge/Nose Cap Reinforced Carbon-Carbon (2.5%)
 - ❑ Crew Module Windows (0.2%)
 - ❑ 10.3% of total area



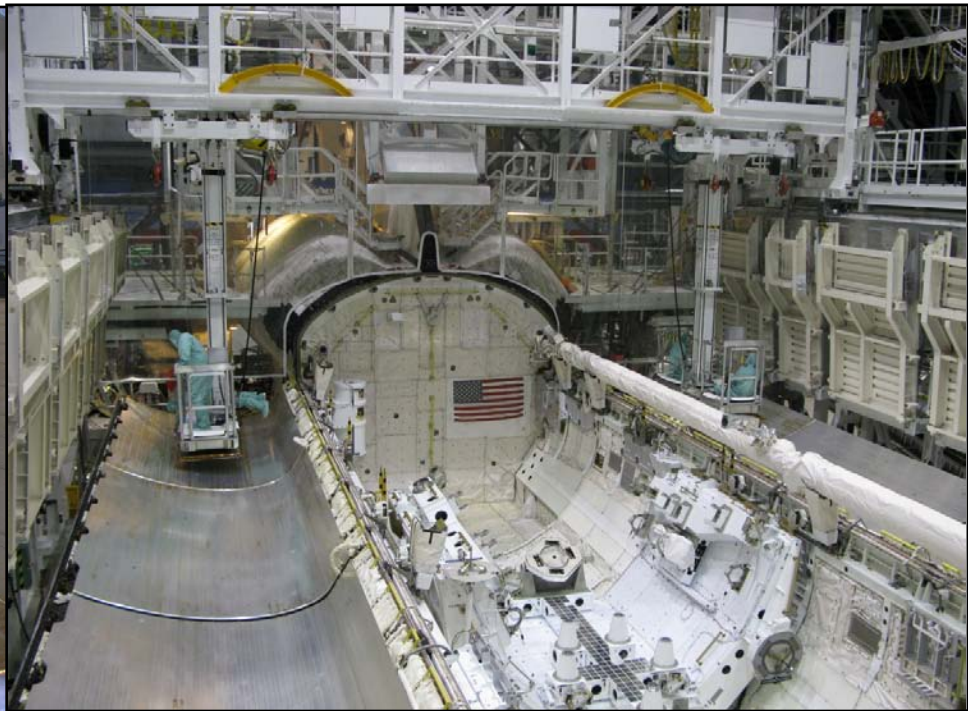
Payload Bay Door Radiators

- ❑ Four panels per door
- ❑ 3.2 x 4.6 m
- ❑ Area ~ 120 m²
- ❑ Aluminum sandwich panels with silver-Teflon thermal tape
- ❑ Open while on orbit (radiators exposed to MMOD environment)
- ❑ Closed for ascent/entry (radiators protected)

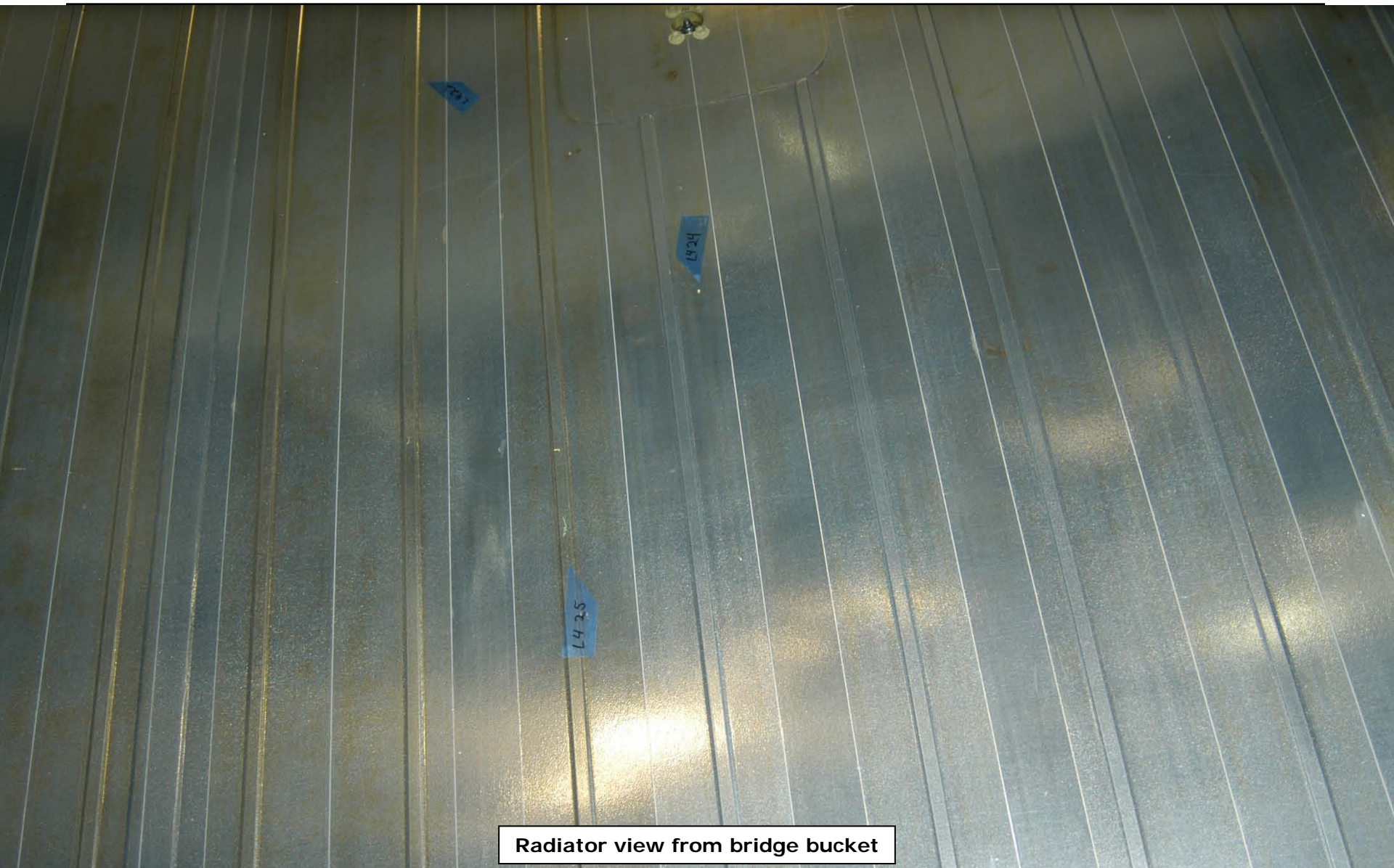


Payload Bay Door Radiators: Inspection

- ❑ Radiator dent & ding inspections were performed after each mission using a bridge crane and 2 platforms.
- ❑ Required contamination suits



Payload Bay Door Radiators: Inspection

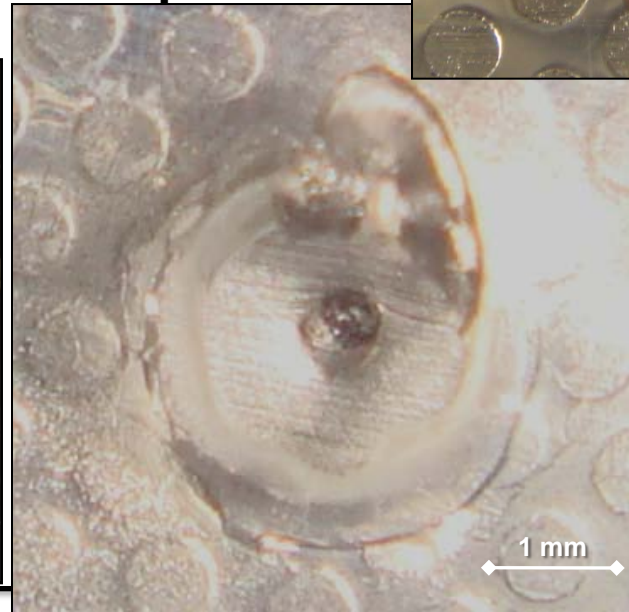
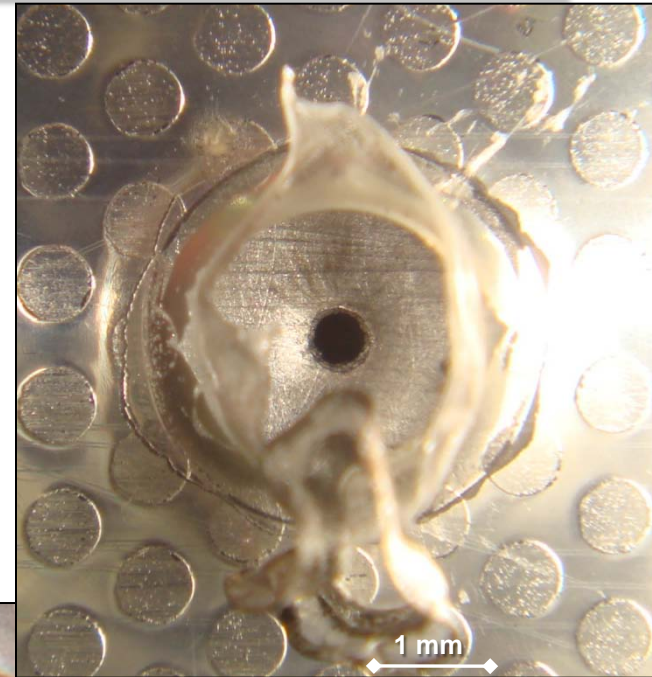


Radiator view from bridge bucket



Payload Bay Door Radiators: Sampling

- ❑ 1 face sheet hole was observed (average) per mission. Thermal tape removed during repair is saved for SEM/EDS analysis. Material around face sheet hole was also recovered.
- ❑ Face sheet craters were the most commonly reported damage feature. Sampling was performed with Reprisil® vinyl polysiloxane impression material.



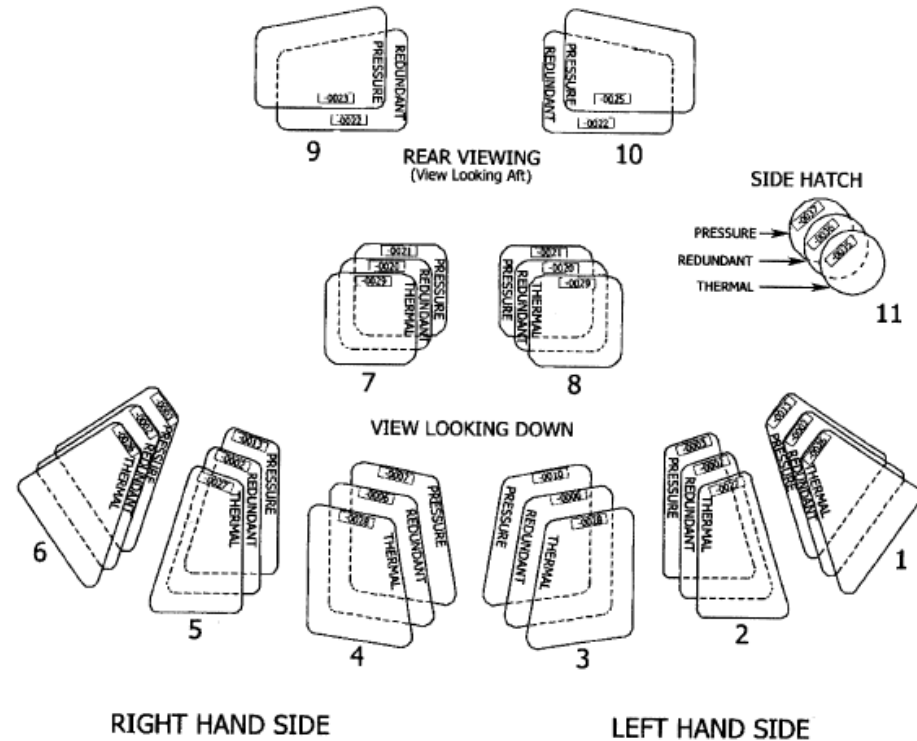
Payload Bay Door Radiators: Sampling

- ❑ Radiator tape damage (tape holes) were reported less frequently than face sheet craters, probably due to observational bias or oversight. Small defects may have been perceived as insignificant and overlooked. Thermal tape removed during repair is saved for SEM/EDS analysis.



Crew Module Windows

- ❑ 11 windows (~3.6 m² total area)
- ❑ Three pane design (Thermal, Redundant, and Pressure)
- ❑ Thermal pane material = fused silica



Reference:
Orbiter Window
Inspection
Familiarization,
May 22, 2006

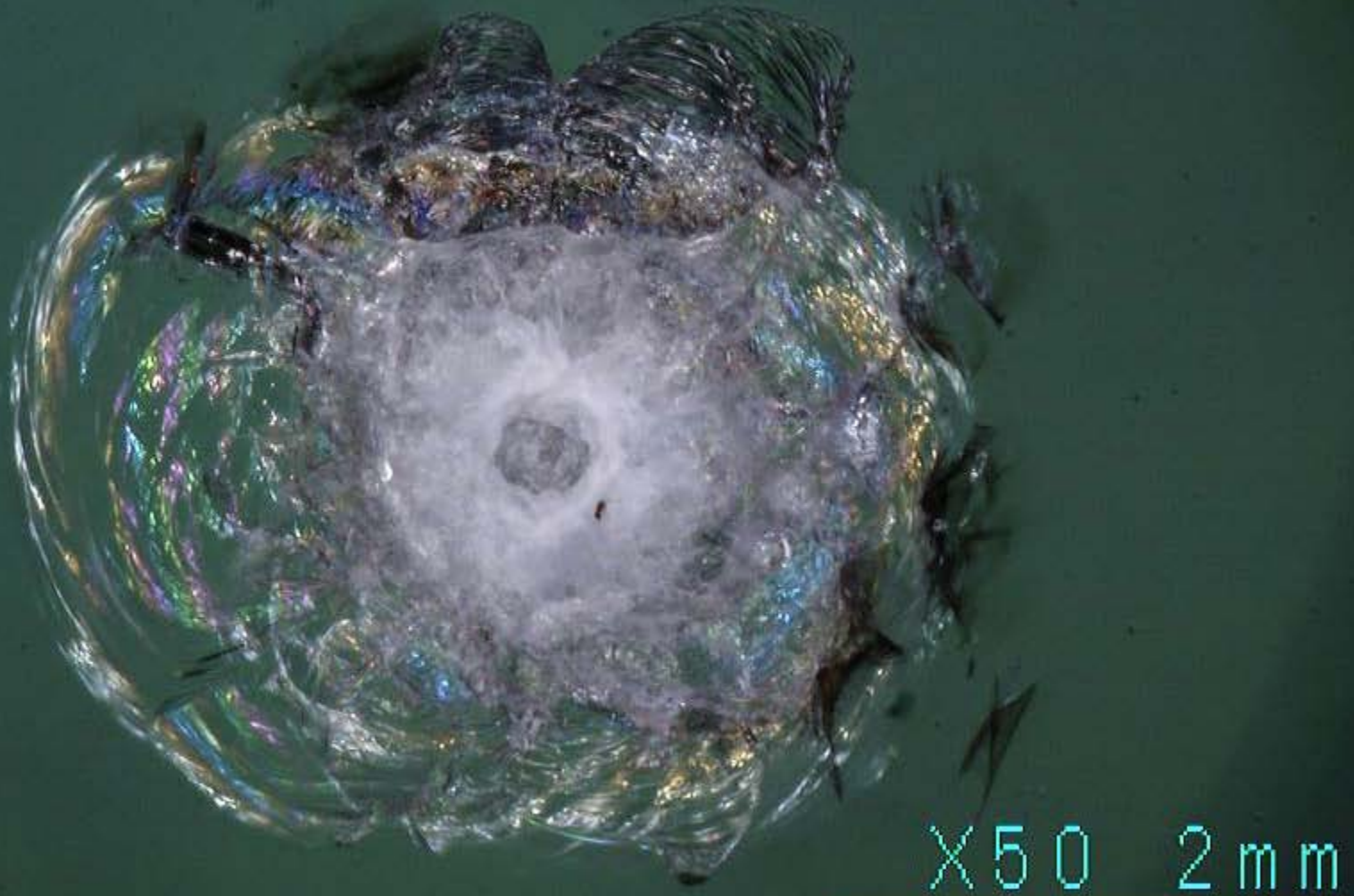


Crew Module Windows: Inspection

- ❑ Inspection access by platform. Awkward reaches necessary for complete inspection.



Crew Module Windows: Inspection

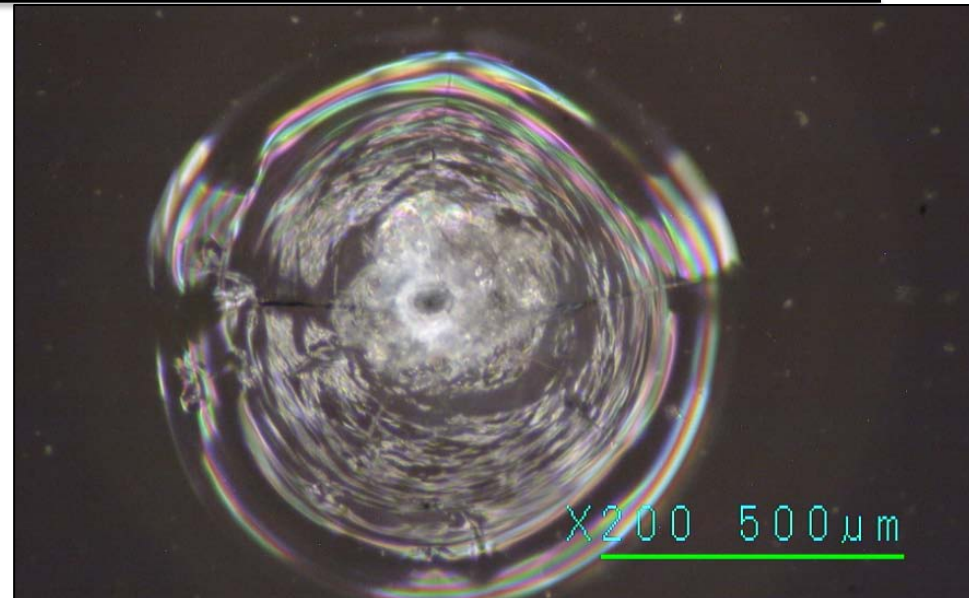


Window 1 from STS-123 (OV-105/Flight 21)

Crew Module Windows: Inspection

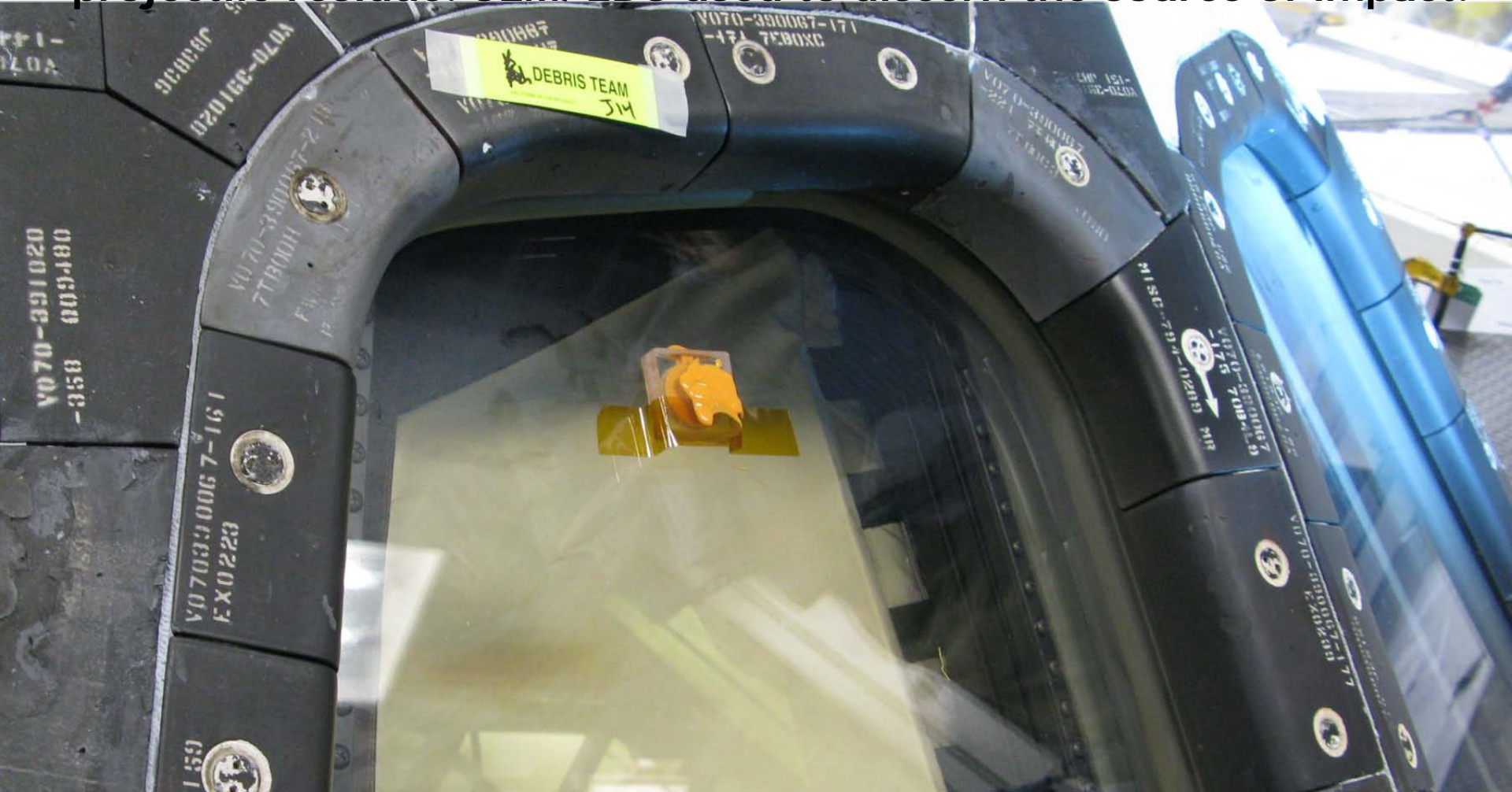
□ Impact features down to **100 μ m in diameter** were easy to detect on the vehicle with clean windows and good lighting.

□ New impacts on W1 and W6 (LH & RH sides) displace plume deposits from Solid Rocket Booster separation motor firings...distinctive radial pattern is easy to see.

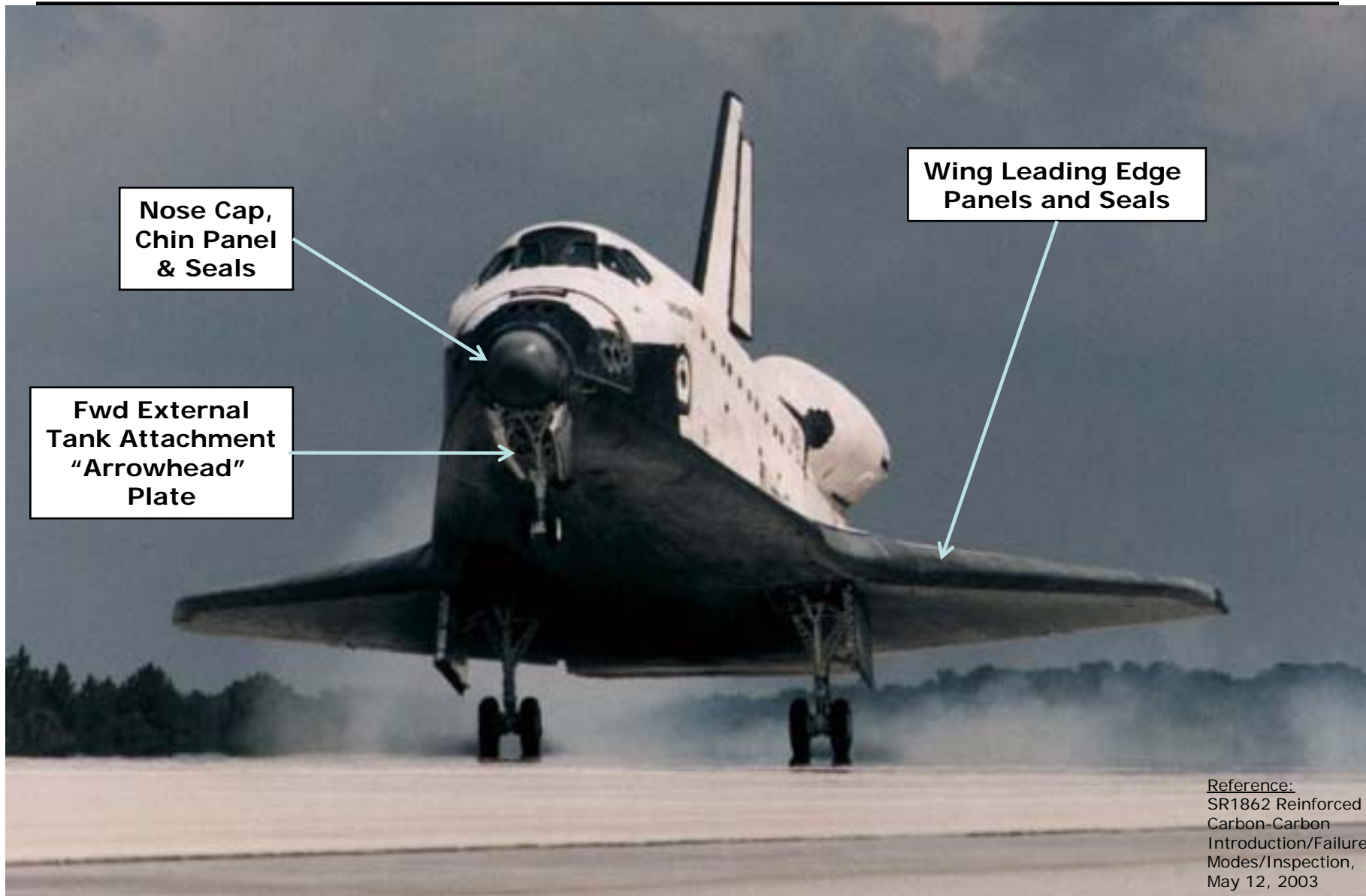


Crew Module Windows: Sampling

- Reprosil® vinyl polysiloxane impression material was used on suspected MMOD sites to measure crater features & extract projectile residue. SEM/EDS used to discern the source of impact.



Leading Edge Structural System/RCC



Nose Cap,
Chin Panel
& Seals

Fwd External
Tank Attachment
"Arrowhead"
Plate

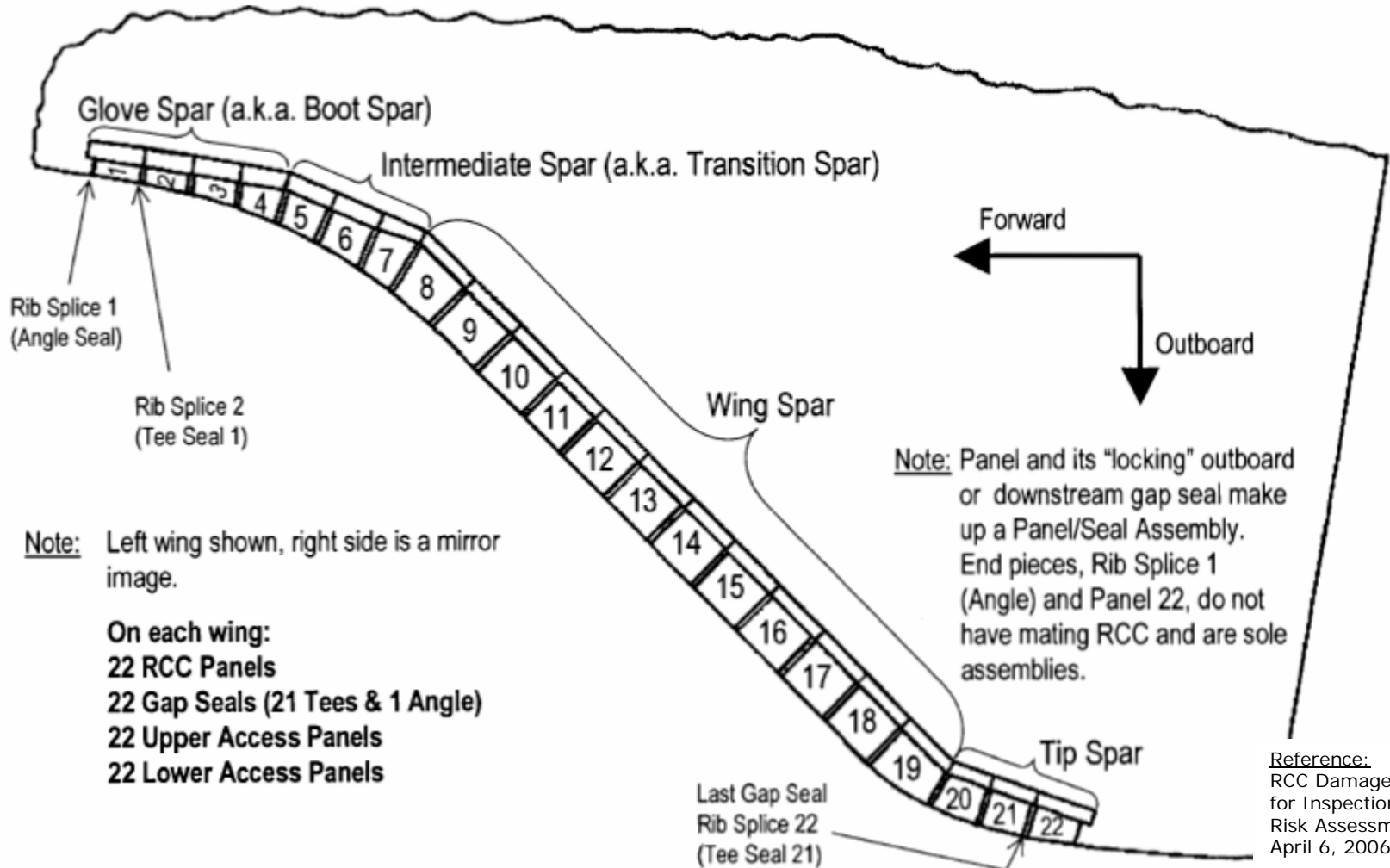
Wing Leading Edge
Panels and Seals

Reference:
SR1862 Reinforced
Carbon-Carbon
Introduction/Failure
Modes/Inspection,
May 12, 2003



Leading Edge Structural System/RCC

- ❑ Wing Leading Edge Panels
- ❑ 22 Panels and Seals per Wing (total area $\approx 35.7 \text{ m}^2$)



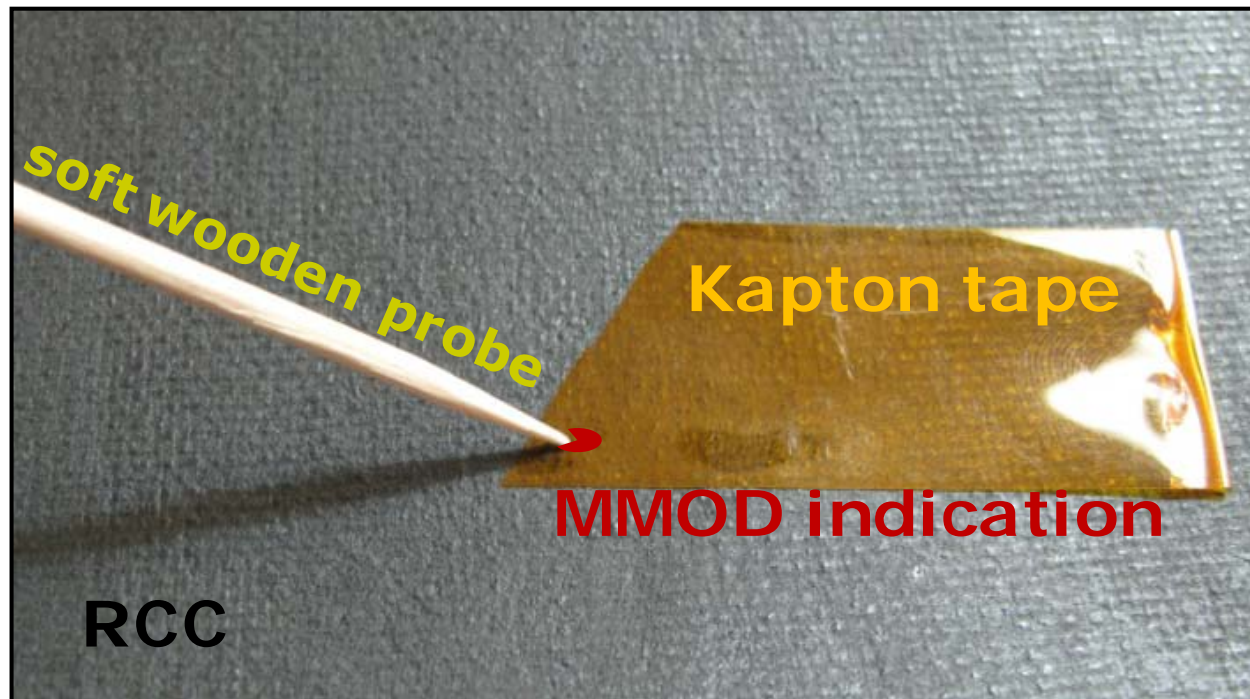
Leading Edge Structural System/RCC: Inspection

- ❑ Inspection access by platform. Overhead reaches necessary for complete inspection.
- ❑ MMOD impacts in RCC produce distinctive damage features.



Leading Edge Structural System/RCC: Sampling

- ❑ Suspected MMOD impact sites were sampled with a tape pull technique. Projectile residue on tape was analyzed with SEM/EDS to discern the source.



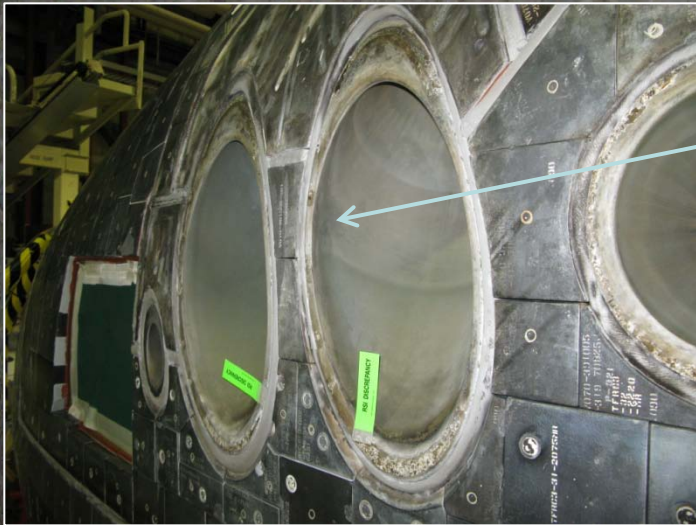
Thermal Protection System (TPS) Tiles

- ❑ Hypervelocity impact features in LI-900 TPS tend to have internal cavities that are larger than the entry hole.
- ❑ Difficult to sample on the vehicle. In a few instances scrapped tiles were removed and MMOD damage sites cored for direct analysis in the SEM/EDS



Thruster Nozzles: Reaction Control System

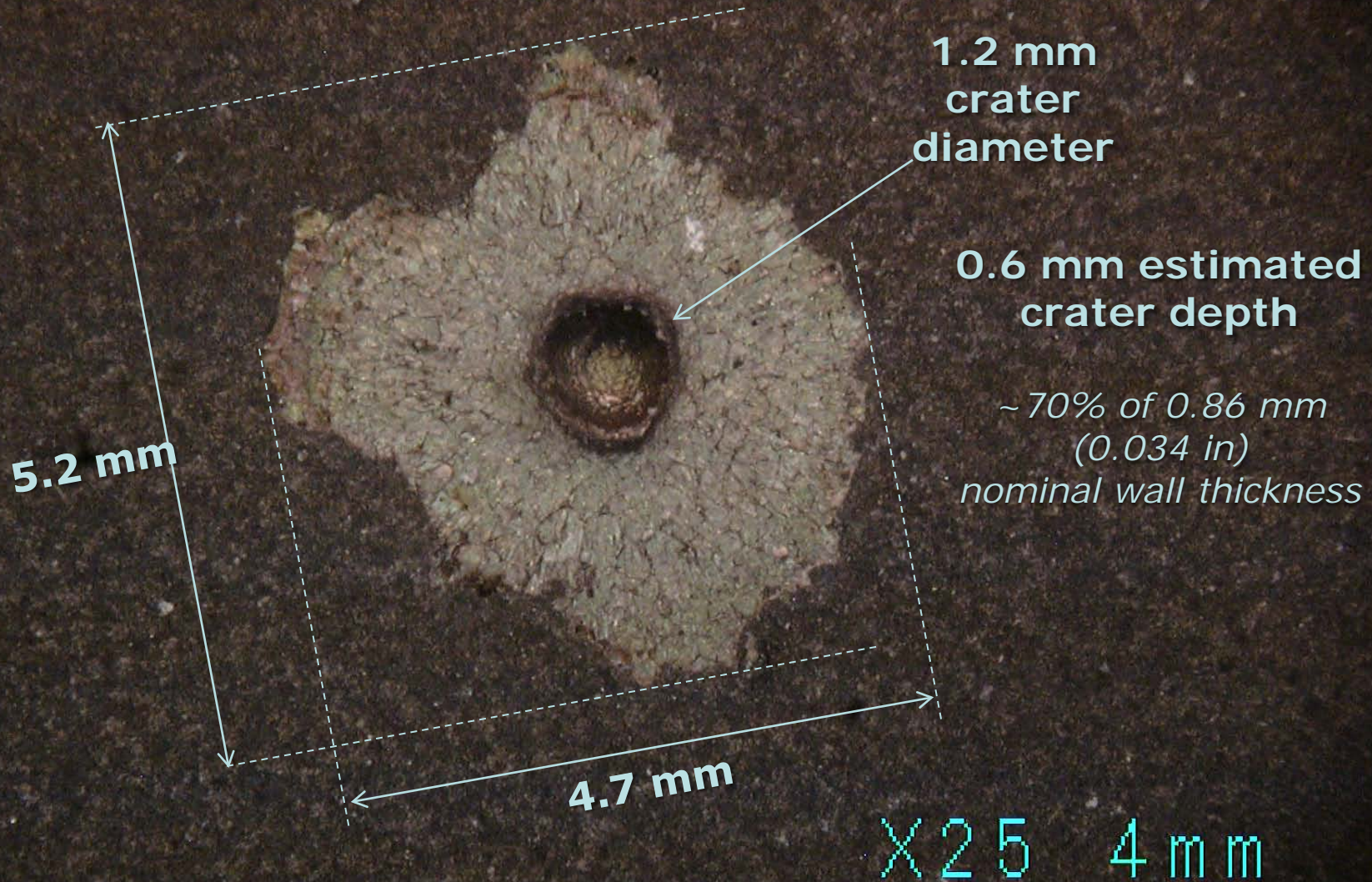
- ❑ Crater in C103 Niobium alloy
- ❑ Distinctive coating loss and central crater



X25 4mm

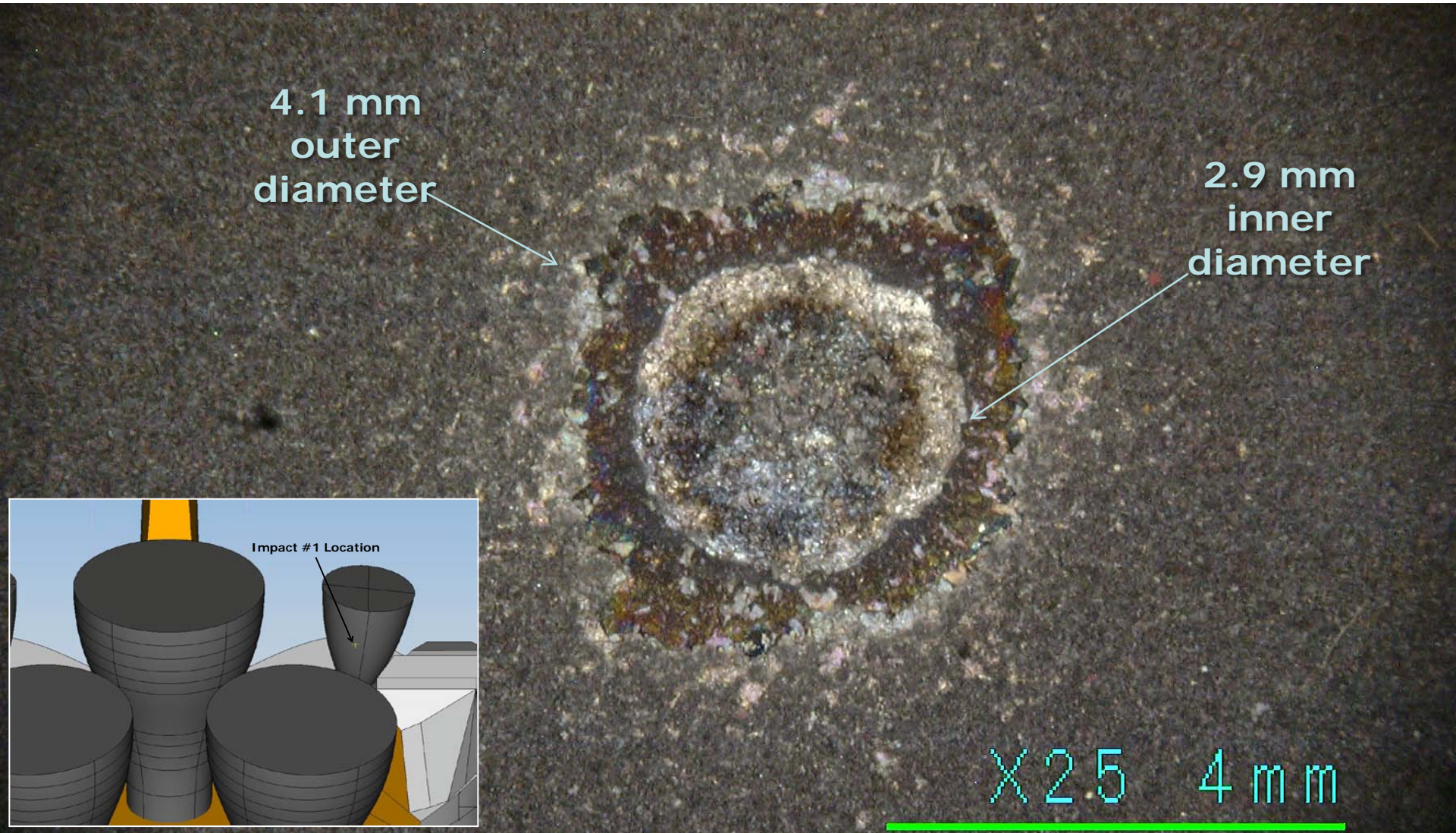
Thruster Nozzles: Orbital Maneuvering System

□ Impact in OMS main engine nozzle (entry crater)



Thruster Nozzles: Orbital Maneuvering System

- Impact in OMS main engine nozzle (back side damage)



Database Overview: Home Page

Shuttle Hypervelocity Impact Database - Home

Crew Module Windows

Number of Records - 1894

[Window Impact Data](#)

[Window Impact Stats](#)

[Window Replacement Data](#)

[Replacements per Mission](#)

[Replacements per Mission-Day](#)

[Replacement History](#)

Payload Bay Door Radiators

Number of Records - 604

[Radiator Impact Data](#)

[Radiator Impact Stats](#)

[Facesheet Perforation Data](#)

[Facesheet Perforations](#)

[Facesheet Perfs per Mission-Day](#)

RCC, FRSI & other areas

Number of Records - 453

[Impact Data](#)

Database Curator:

Jim Hyde 281-244-5068

Last Update:

24-Aug-2011

[Change Log](#)



Crew Module Window Summary

Distinct Missions: 89 *missions with window impacts*

Total Missions: 133 *(STS-1 thru STS-133)*

Total DB Records = 1894

Impact Sources

Unknown*	1315	69%
Micrometeoroids (MM)	262	14%
Orbital Debris (OD)	317	17%
Total	1894	

* unknown assumed to be meteoroids

Damage Feature Size

Feature	AVG (mm)	MAX (mm)	MIN (mm)
Crater Length	0.480	13.434	0.050
Crater Width	0.429	8.966	0.036
Crater Depth	0.050	0.828	0.011

Estimated Projectile Sizes

Damage Feature	AVG (mm)	MAX (mm)	MIN (mm)
Crack/Flaw Diameter	0.028	0.309	0.0057
Crater Depth	0.023	0.406	0.0052

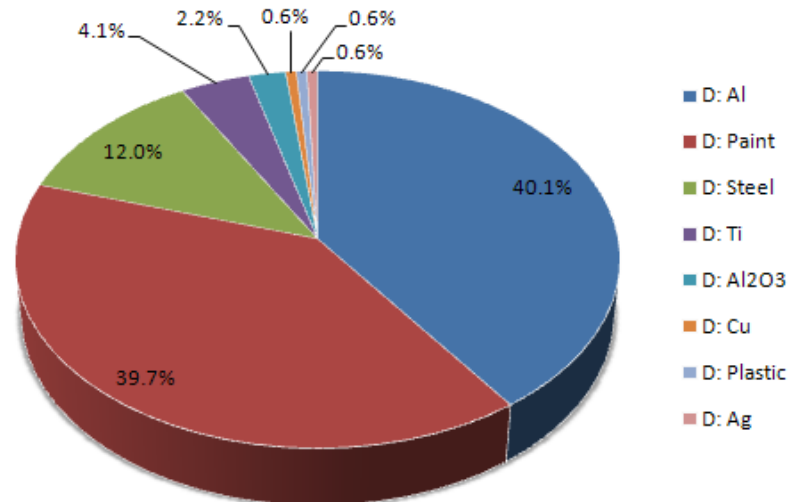
Replacements (thru STS-133)

total replacements (MMOD)	183
replacements/mission	1.35
replacements/mission-day	0.14

OD Sources

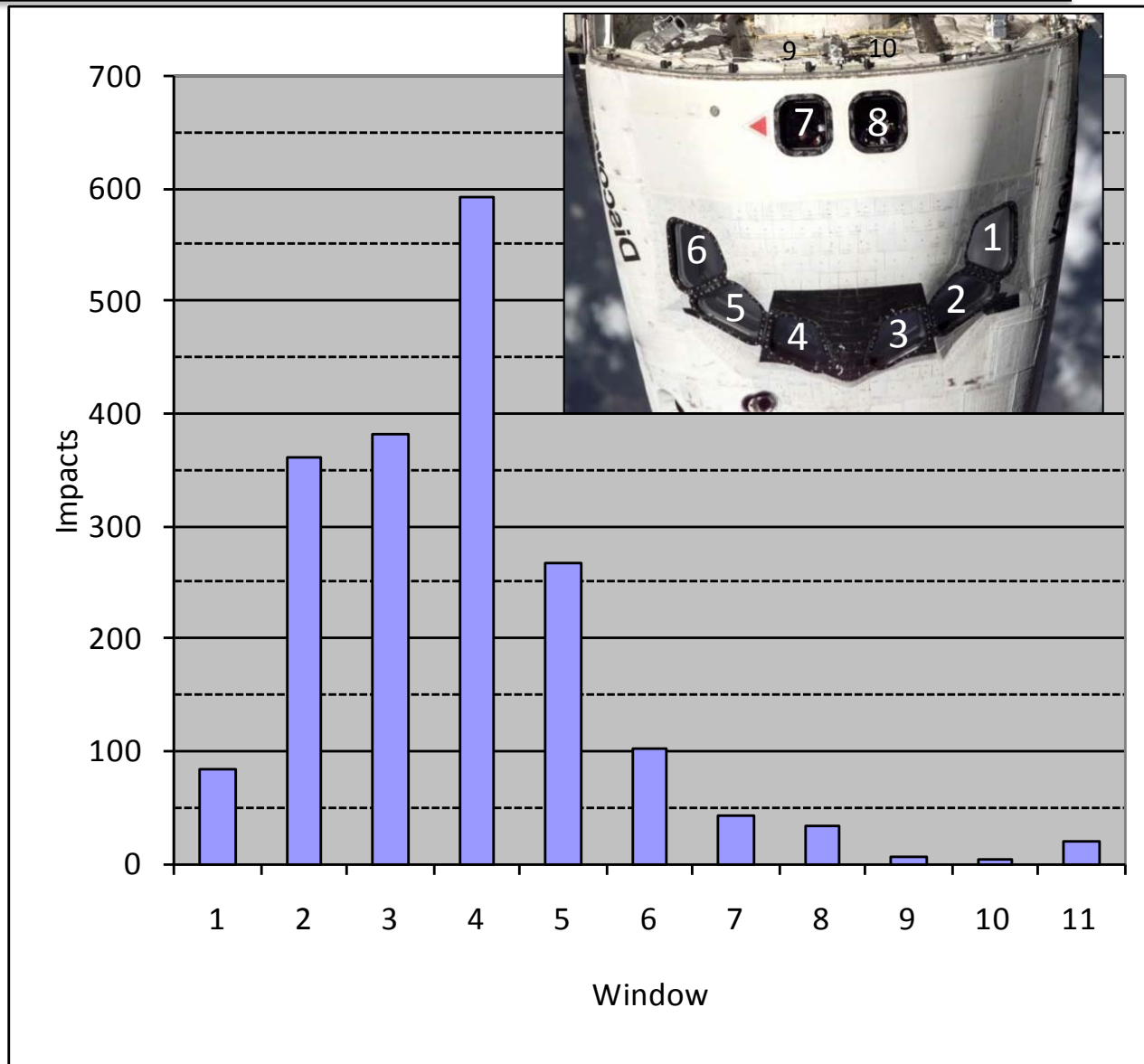
D: Al	127
D: Paint	126
D: Steel	38
D: Ti	13
D: Al2O3	7
D: Cu	2
D: Plastic	2
D: Ag	2
D: Na/K	0
D: binders	0
D: waste	0
D: NiCd	0
D: PCboard	0
Total	317

Orbital Debris Sources: Windows

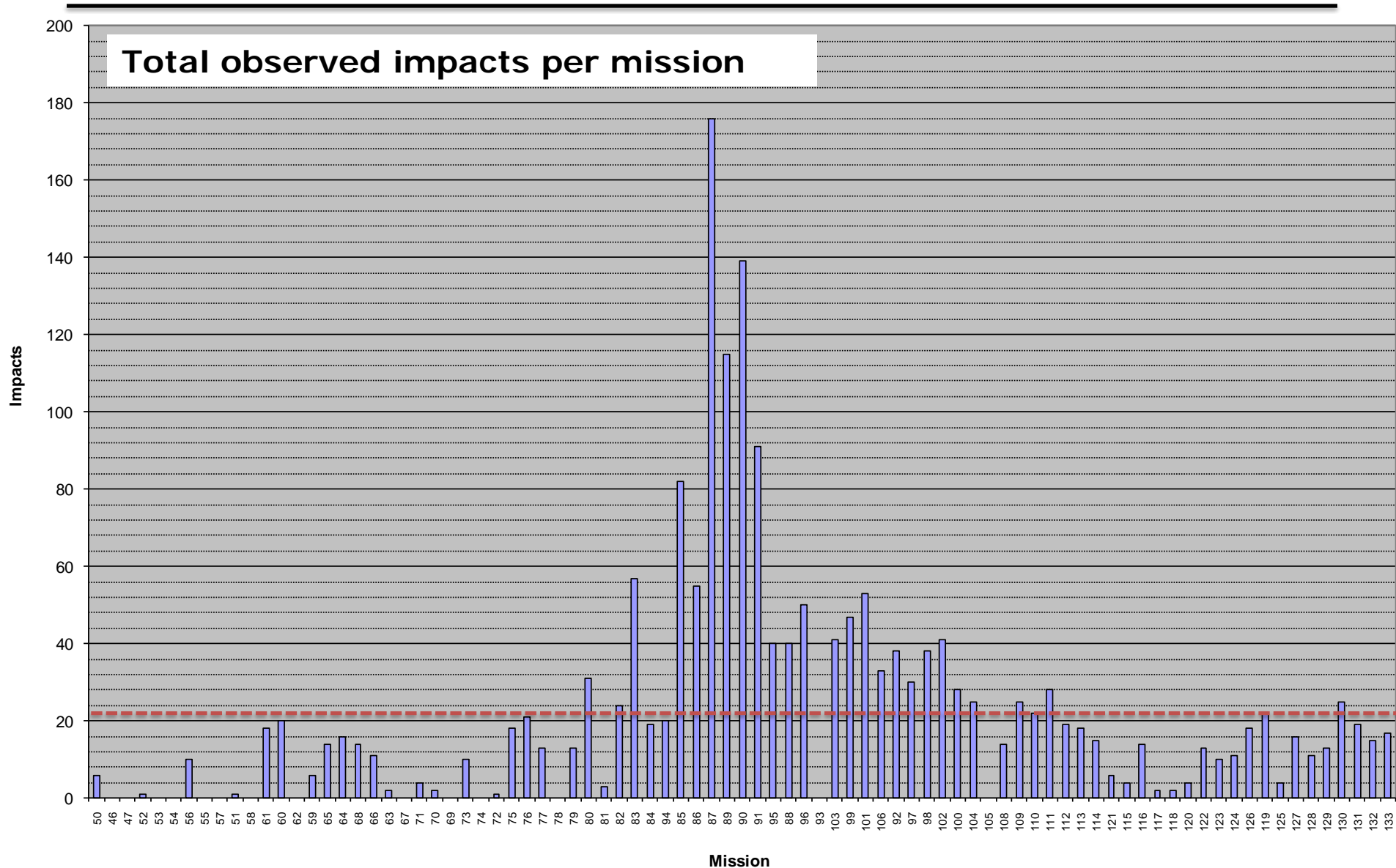


Crew Module Window Data

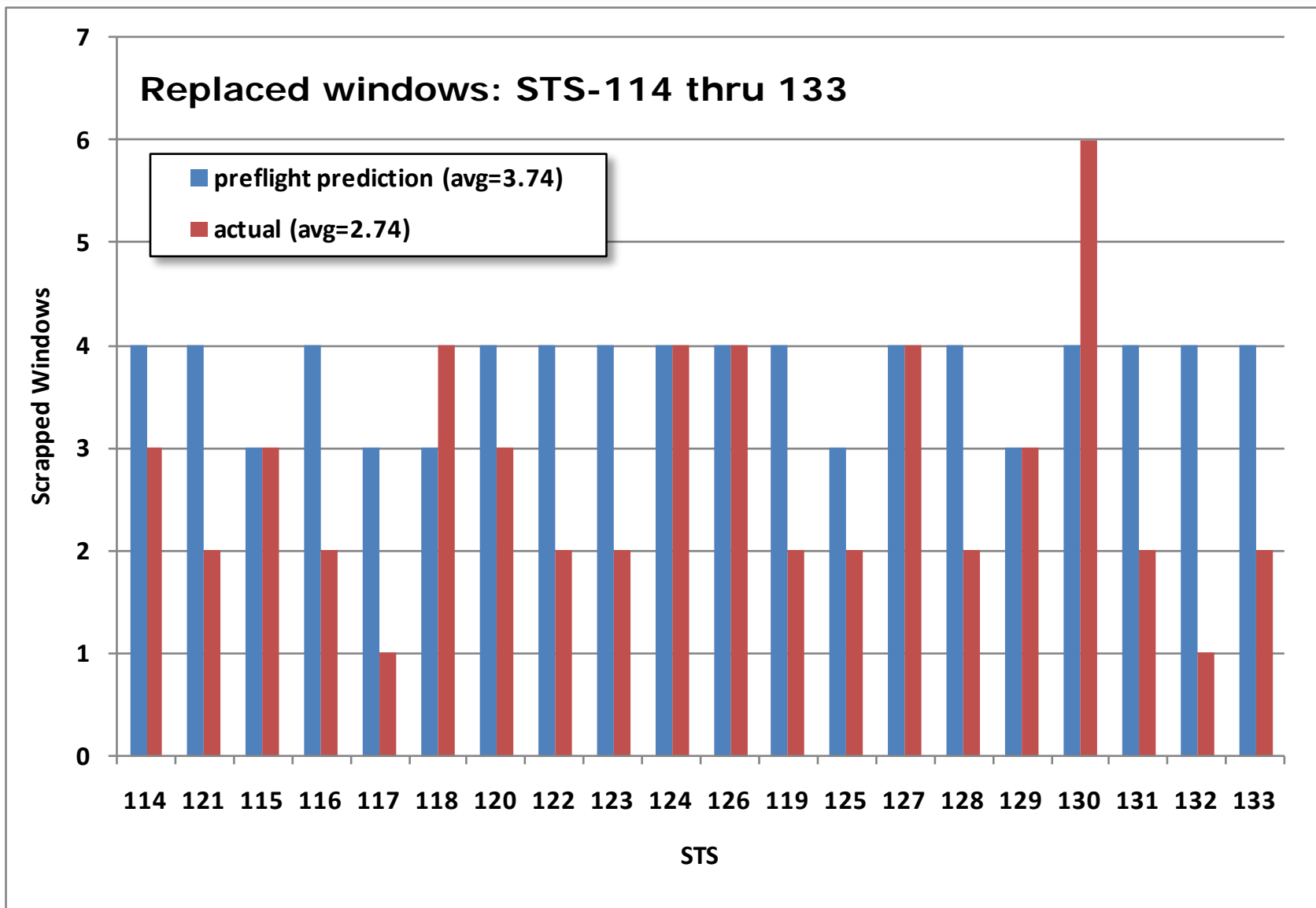
- Total observed impacts per window.
- Distribution at W4 was skewed by a large number of impacts on STS-85 thru STS-91.



Crew Module Window Data



Crew Module Window Data



Payload Bay Door Radiator Summary

Distinct Missions: 73 *missions with radiator impacts*

Total Missions: 133 *(STS-1 thru STS-133)*

Total DB Records = 601

Tape Holes = 137

Facesheet Craters = 388

Facesheet Holes = 76

Impact Sources

Unknown*	427	71%
Micrometeoroids (MM)	83	14%
Orbital Debris (OD)	91	15%
Total	601	

* unknowns were assumed to be 60% meteoroids & 40% aluminum

Damage Feature Size

Feature	AVG (mm)	MAX (mm)	MIN (mm)
Tape Hole Diameter	1.90	8.30	0.203
Face Sheet Crater Diameter	0.82	10.57	0.020
Face Sheet Crater Depth	0.11	2.40	0.003
Face Sheet Hole Diameter	1.02	5.54	0.025

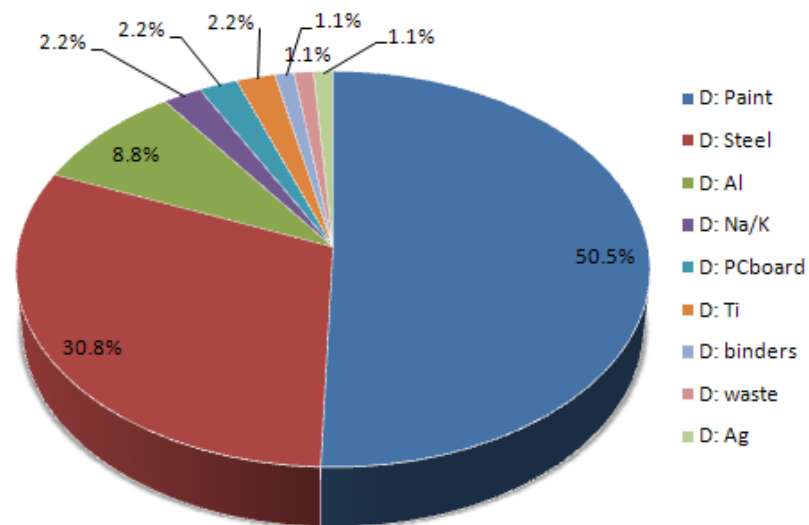
Estimated Projectile Sizes

Damage Feature	AVG (mm)	MAX (mm)	MIN (mm)
Tape Hole	0.25	1.79	0.024
Face Sheet Crater	0.12	1.03	0.053
Face Sheet Hole	0.26	3.84	0.001

OD Sources

D: Paint	46
D: Steel	28
D: Al	8
D: Na/K	2
D: PCboard	2
D: Ti	2
D: binders	1
D: waste	1
D: Ag	1
D: Al2O3	0
D: Cu	0
D: NiCd	0
D: Plastic	0
Total	91

Orbital Debris Sources: Radiators



Payload Bay Door Radiator Data

Home

PAYLOAD BAY DOOR RADIATORS - HYPERVELOCITY IMPACT DATA

STS	Panel	Sample #	Tape Hole Diameter (mm)			Facesheet Damage (mm)			Estimated Impactor Diameter			SEM Particle Type	Assessed Particle Type	SEM/EDXA Results	Particle Density (g/cm³)	Impact Velocity (km/s)	Notes		
			length	width		length	width	depth	Tape Hole Diam (mm)	Face Sheet Crater Depth (mm)	Face Sheet Hole Diam (mm)								
119	LH1	19	--	x	--	0.19	x	0.17	x	0.02	--	0.08	--	U	D: Al	Unknown	2.8	7.14	DR STR-3-37-9770
119	LH1	20	--	x	--	0.24	x	0.24	x	0.07	--	0.12	--	U	D: Al	Unknown	2.8	7.14	STR-3-37-9770
119	LH1	21	--	x	--	0.51	x	0.51	x	hole	--	--	0.04	D	D: steel	Fe, Ti, Fe-Cr-Ni	7.9	7.14	STR-3-37-9770
119	LH1	22	--	x	--	0.75	x	0.70	x	0.09	--	0.11	--	U	M	Unknown	1.0	23.00	STR-3-37-9770
119	LH1	23	--	x	--	0.20	x	0.19	x	0.10	--	0.11	--	U	M	Unknown	1.0	23.00	STR-3-37-9770
119	LH1	24	0.63	x	0.62	--	x	--	x	--	0.08	--	--	U	M	Unknown	1.0	23.00	STR-3-37-9770
119	LH2	20	0.56	x	0.57	--	x	--	x	--	0.07	--	--	U	M	Unknown	1.0	23.00	DR STR-3-37-9771
119	LH3	27	--	x	--	0.40	x	0.37	x	0.08	--	0.10	--	U	M	Unknown	1.0	23.00	DR STR-3-37-9772
119	LH3	28	0.54	x	0.54	--	x	--	x	--	0.07	--	--	U	D: Al	Unknown	2.8	7.14	DR STR-3-31-9772
119	LH4	20	--	x	--	0.15	x	0.14	x	0.04	--	0.07	--	U	M	Unknown	1.0	23.00	DR STR-3-37-9773
119	LH4	21	0.55	x	0.54	--	x	--	x	--	0.07	--	--	U	M	Unknown	1.0	23.00	DR STR-3-37-9773
119	RH1	14	--	x	--	0.64	x	0.57	x	0.25	--	0.20	--	U	D: Al	Unknown	2.8	7.14	STR-3-37-9766
119	RH1	15	--	x	--	0.61	x	0.56	x	0.76	--	0.45	--	U	D: Al	Unknown	2.8	7.14	STR-3-37-9766
119	RH1	16	--	x	--	0.31	x	0.34	x	0.05	--	0.08	--	U	M	Unknown	1.0	23.00	STR-3-37-9766
119	RH1	18	--	x	--	0.16	x	0.15	x	0.02	--	0.07	--	U	M	Unknown	1.0	23.00	STR-3-37-9798
119	RH2	14	--	x	--	0.47	x	0.43	x	0.08	--	0.10	--	U	M	Unknown	1.0	23.00	STR-3-37-9767
119	RH2	15	--	x	--	0.36	x	0.35	x	0.05	--	0.08	--	U	M	Unknown	1.0	23.00	STR-3-37-9767
119	RH3	24	--	x	--	0.43	x	0.43	x	0.06	--	0.10	--	U	D: Al	Unknown	2.8	7.14	STR-3-37-9768
119	RH3	25	--	x	--	0.63	x	0.64	x	0.11	--	0.11	--	U	M	Unknown	1.0	23.00	STR-3-37-9768
119	RH4	19	--	x	--	0.35	x	0.31	x	0.06	--	0.08	--	U	M	Unknown	1.0	23.00	STR-3-37-9769
125	LH1	34	--	x	--	2.51	x	2.29	x	0.05	--	0.14	--	U	D: Al	Unknown	2.8	3.85	STR 4-31-8240
125	LH1	35	--	x	--	1.88	x	1.55	x	0.10	--	0.19	--	U	D: Al	Unknown	2.8	3.85	STR 4-31-8240
125	LH2	27	--	x	--	2.57	x	2.46	x	0.08	--	0.10	--	U	M	Unknown	1.0	23.00	STR 4-31-8201
125	LH2	28	--	x	--	3.86	x	2.36	x	0.13	--	0.12	--	U	M	Unknown	1.0	23.00	STR 4-31-8201
125	LH3	32	--	x	--	1.07	x	0.81	x	0.08	--	0.18	--	U	D: Al	Unknown	2.8	3.85	STR 4-31-8241
125	LH3	33	1.68	x	1.04	--	x	--	x	--	0.16	--	--	U	M	Unknown	1.0	23.00	STR 4-31-8241
125	LH3	34	--	x	--	2.46	x	2.41	x	0.10	--	0.11	--	U	M	Unknown	1.0	23.00	STR 4-31-8241
125	LH4	29	--	x	--	2.39	x	1.70	x	0.10	--	0.19	--	U	D: Al	Unknown	2.8	3.85	STR 4-31-8242
125	LH4	30	--	x	--	1.65	x	1.70	x	0.08	--	0.10	--	U	M	Unknown	1.0	23.00	STR 4-31-8242
125	RH2	24	--	x	--	0.64	x	0.64	x	hole	--	--	0.00	U	M	Unknown	1.0	23.00	STR 4-31-8205
125	RH3	33	--	x	--	1.02	x	1.02	x	hole	--	--	0.01	U	M	Unknown	1.0	23.00	STR 4-31-8204
125	RH4	31	--	x	--	0.48	x	0.69	x	0.15	--	0.22	--	U	D: Al	Unknown	2.8	3.85	STR 4-31-8202
127	LH1	28	--	x	--	0.53	x	0.53	x	0.08	--	0.10	--	U	M	Unknown	1.0	23.00	STR-5-24-5947
127	LH1	30	1.91	x	0.74	--	x	--	x	--	0.16	--	--	U	M	Unknown	1.0	23.00	STR-5-24-5947
127	LH4	18	3.07	x	3.10	--	x	--	x	--	0.41	--	--	U	D: Al	Unknown	2.8	7.15	STR-5-24-5949
127	LH4	20	1.09	x	0.99	--	x	--	x	--	0.14	--	--	U	D: Al	Unknown	2.8	7.15	STR-5-24-5949
127	RH2	18	--	x	--	0.28	x	0.25	x	0.03	--	0.08	--	U	D: Al	Unknown	2.8	7.15	STR-5-24-5945
127	RH2	19	--	x	--	0.25	x	0.30	x	0.03	--	0.06	--	U	M	Unknown	1.0	23.00	STR-5-24-5946
127	RH3	16	--	x	--	0.86	x	0.89	x	hole	--	--	0.16	D	D: paint	Fe, Cu, F, Ti, sm Al spheres	2.5	7.15	STR-5-24-5943
127	RH3	17	--	x	--	0.41	x	0.36	x	0.05	--	0.08	--	U	M	Unknown	1.0	23.00	STR-5-24-5944
127	RH4	45	--	x	--	0.33	x	0.33	x	0.05	--	0.10	--	U	D: Al	Unknown	2.8	7.15	STR-5-24-5942
127	RH4	46	--	x	--	0.25	x	0.30	x	0.03	--	0.06	--	U	M	Unknown	1.0	23.00	STR-5-24-5942
127	RH4	47	--	x	--	0.33	x	0.51	x	0.13	--	0.12	--	U	M	Unknown	1.0	23.00	STR-5-24-5942
127	RH4	48	--	x	--	0.38	x	0.36	x	0.15	--	0.16	--	U	D: Al	Unknown	2.8	7.15	STR-5-24-5942
128	LH1	25	--	x	--	0.90	x	0.86	x	0.20	--	0.14	--	U	M	Unknown (Si, Ag, Cr, Ni, Sr)	1.0	23.00	STR-3-38-9837
128	LH2	21	--	x	--	0.51	x	0.51	x	hole	--	--	0.04	U	D: Al	Unknown	2.8	7.15	STR-3-38-9838
128	LH4	22	--	x	--	1.02	x	1.02	x	hole	--	--	0.23	D	D: paint	Cr, Fe, Ti	2.5	7.15	Str-3-38-9840
128	LH4	25	--	x	--	0.48	x	0.48	x	0.02	--	0.07	--	U	M	Unknown	1.0	23.00	Str-3-38-9839
128	LH4	26	--	x	--	0.46	x	0.46	x	0.02	--	0.12	--	U	D: Al	Unknown	2.8	7.15	Str-3-38-9839
128	LH4	27	2.54	x	2.54	--	x	--	x	--	0.33	--	--	U	D: Al	Unknown	2.8	7.15	Str-3-38-9839
128	LH4	28	--	x	--	0.58	x	0.58	x	0.07	--	0.09	--	U	M	Unknown	1.0	23.00	Str-3-38-9839
128	RH1	19	--	x	--	0.50	x	0.56	x	0.37	--	0.26	--	D	D: Al	Al, Si, trace Fe, Cu	2.8	7.15	STR-3-38-9841
128	RH2	16	--	x	--	0.47	x	0.51	x	0.13	--	0.12	--	U	M	Unknown	1.0	23.00	STR-3-38-9842
128	RH3	26	--	x	--	0.91	x	0.91	x	0.11	--	0.11	--	U	M	Unknown	1.0	23.00	STR-3-38-9867
128	RH3	30	--	x	--	0.60	x	0.56	x	0.11	--	0.14	--	U	D: Al	Unknown	2.8	7.15	STR-3-38-9847
128	RH4	20	0.44	x	0.41	--	x	--	x	--	0.06	--	--	U	D: Al	Unknown	2.8	7.15	None



Summary & Forward Work

- ❑ **Excel based list of shuttle inspection results**
 - ❑ **Crew Module Windows**
 - ❑ **Payload Bay Door Radiators**
 - ❑ **Thermal Protection System**
- ❑ **SEM/EDS results included**
- ❑ **Estimated particle diameters**

- ❑ **Forward Work**
 - ❑ **Conversion to web based application**
 - ❑ **Integration with image database**
- ❑ **Additional Datasets**
 - ❑ **ISS returned hardware dataset**
 - ❑ **HST WFPC2 radiator inspection**

